# THE FAIRBANKS HALO OF APRIL 27, 1966

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## ABSTRACT

A description of a magnificent display of solar haloes visible over Fairbanks, Alaska, is presented and a photographic record of the anthelic arcs is used to compare these arcs with the two principal theories of Wegener and Hastings. The temperature range and interval of possible crystal formation is inferred from the halo forms and compared with aerological data at the time of the display.

## 1. INTRODUCTION

The appearance of extensive displays of solar haloes is an uncommon event in most parts of the world away from the polar ice-caps. The display reported here constitutes one of the more impressive appearances, comparing favorably with the classics of history, such as those described by Pernter and Exner [16] and those analyzed by Visser [19]. It was visible from the general vicinity of Fairbanks, Alaska and the observations here reported were made from nearby College (64°51′ N., 147°50′ W.), between 1300 and 1530 Alaskan Standard Time (UT−10 hr.), on April 27, 1966.

The time of the first appearance of the haloes is not known, but they were visible by 1230 and certainly well developed by 1300 AST, appearing in very filmy cirriform cloud covering most of the sky. The particular arcs that appear in such events depend on the type and orientation of the ice crystals present, and on the solar altitude, $h_s$. We refer the reader to the literature [2, 3, 5, 6, 8, 14, 16, 17, 19, 20] for further details, particularly to the exhaustive review by Visser [19], who describes over 50 different forms. The ice crystals producing the haloes usually occur in high, cirriform cloud, but sometimes, especially over the polar ice-caps, the crystals occur very close to the ground [4, 11, 21] giving rise to exceptionally brilliant displays.

## 2. DESCRIPTION

The accompanying photographs show the display recorded by a Panon Widelux camera with a 140° horizontal view (fig. 1), and by an all-sky camera [1] (fig. 2). The

[1] The all-sky camera is designed for auroral photography. It consists of a convex mirror reflecting the entire sky via a plane mirror into the camera. The radial scale is not linear or cosine.

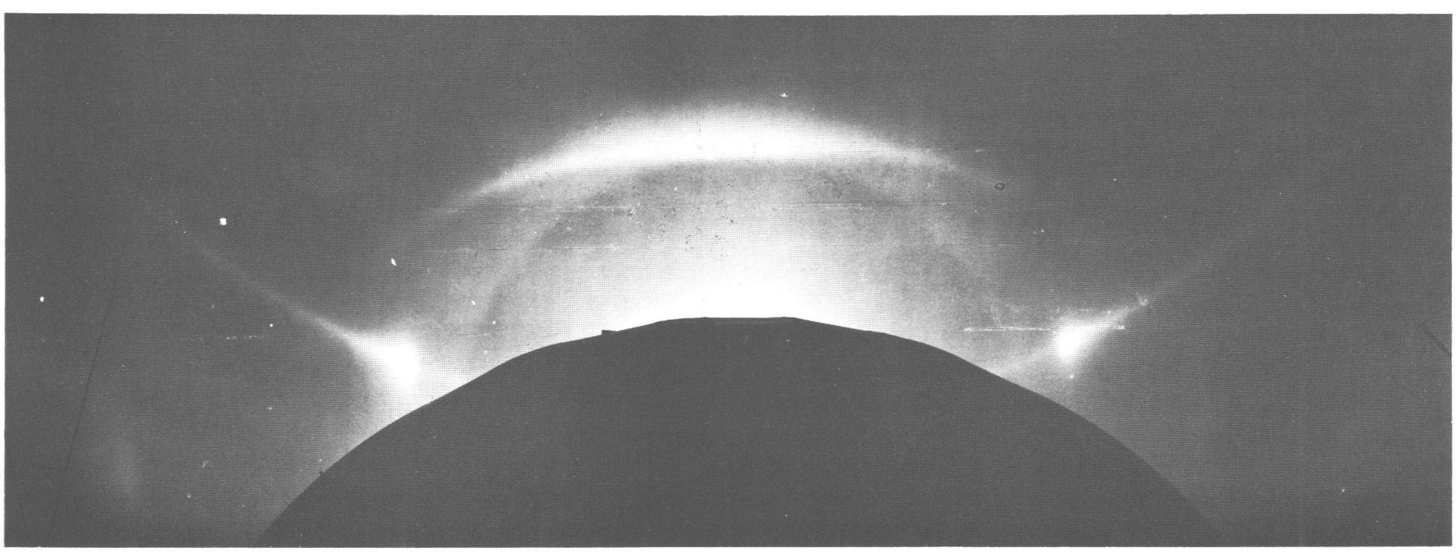

FIGURE 1.—Display seen by Panon Widelux camera with 140° horizontal view. High Speed Ektachrome (160 ASA) $f$:11, 1/250 sec.

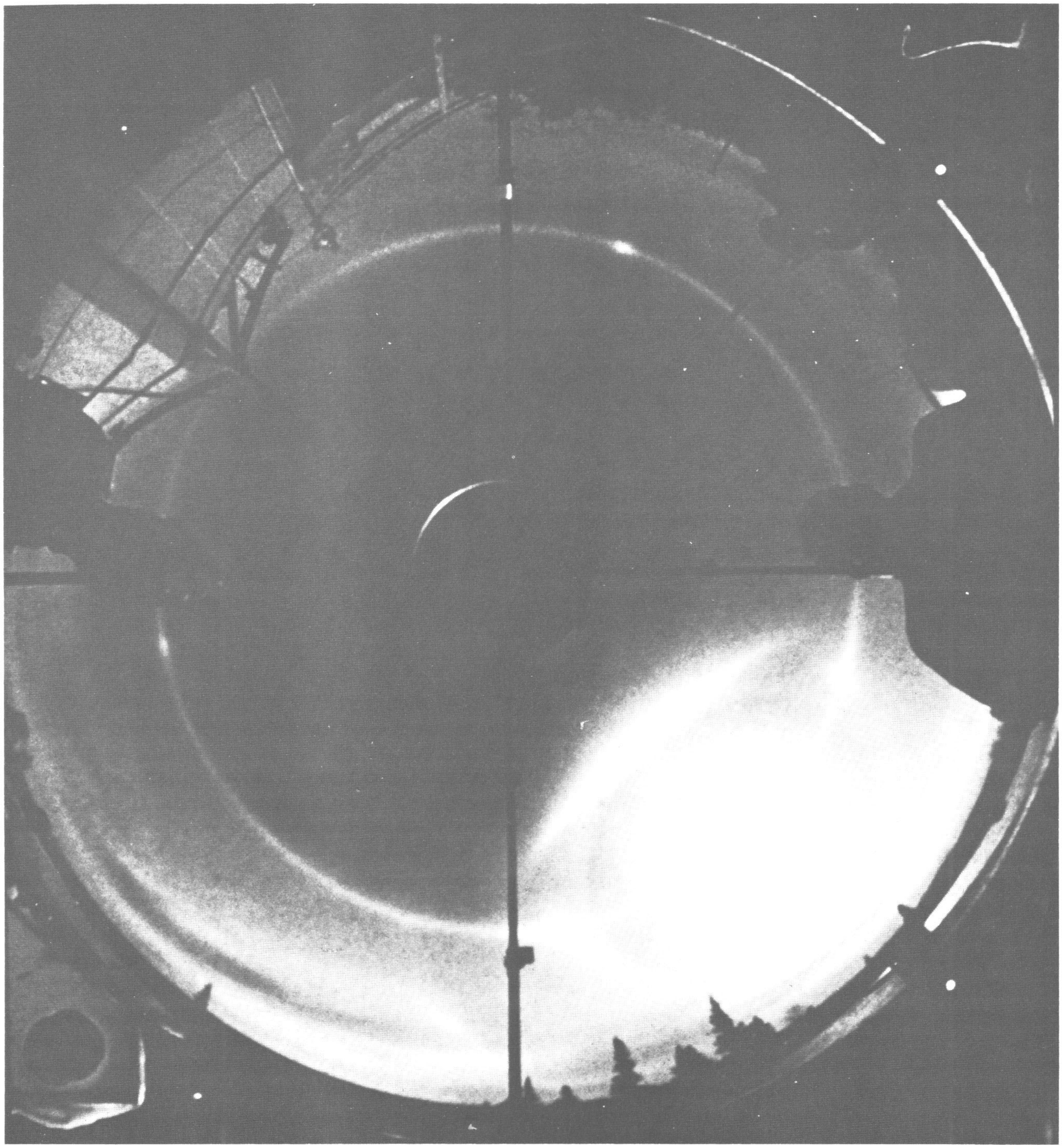

FIGURE 2.—Display seen by all-sky camera, with Pentax camera, 55-mm. Tachomar lens, High Speed Ektachrome at 1/500 sec.

various arcs are identified in the following description by reference to figures 3 and 4.

At 1300 AST ($h_s$=37.6°), the display was essentially that shown in figure 3. The most brilliant haloes were the white, complete parhelic circle (4), the colored 22°-parhelia (3) and their white tails superposed over the parhelic circle, and the upper portion of the circumscribed halo (5) and its intense white veil. As is frequently the case, the parhelic circle was appreciably weaker in intensity between the 22°-parhelia and the sun, in comparison with its appearance elsewhere, even toward the anthelic point. Superposed over the parhelic circle were both 120°-paranthelia (10), appearing as bright white knots of light, with no arc extensions. At 1325 AST ($h_s$=36.5°) the azimuth of these was measured at approximately 119° by Prof. W. Mendenhall of the Engineering Department of this University, using a surveyor's level. He also measured the azimuth of the parhelia as approximately 33°

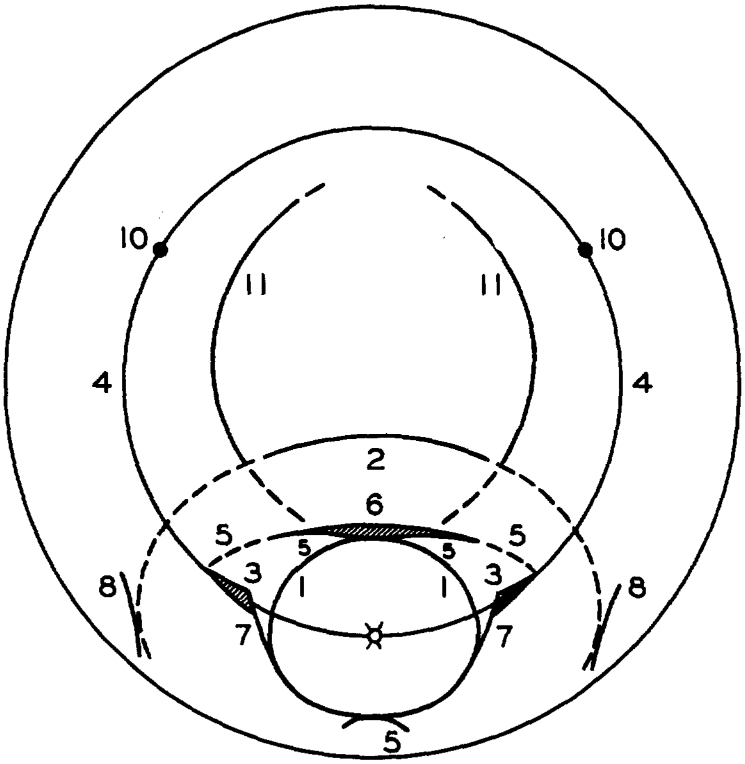


FIGURE 3.—Sketch of display for period 1300–1430 AST ($h_s$=37.6°–32.2°). Based on all-sky camera photograph by T. Ohtake.

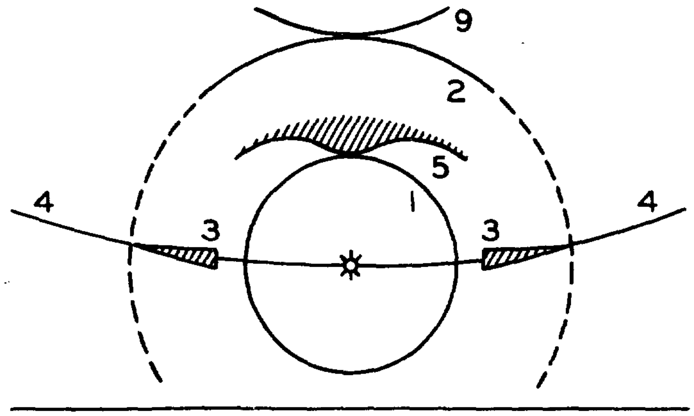


FIGURE 4.—Sketch of display at 1510 AST ($h_s$=28.8°).

from the sun, at the same solar elevation, a figure agreeing excellently with that deduced from Wegener's [20] equations (33.1°).

The circumscribed halo (5) was visible in two parts—the upper and lower contact arcs to the 22°-halo. Both parts were very bright and colored, the lower one being considerably more diffuse than the upper one. The nonminimal refractions (analogous to the tails of the parhelia) produce a white haze on the outside of the focal line of this halo, being exceptionally intense in the upper and lower solar vertical where the arcs are concave away from the sun and the "tails" thus convergent. This accounts for the diffuseness of the sharply curved lower arc. The upper arc did not at first reach the parhelic circle (4) but later did so in a faint extension. The lower arc showed sufficient extension for the change of curvature to be detected, but did not reach the turning point back toward the parhelic circle.

The 22°-halo (1) was very weak, though always detectable throughout the entire display. At first sight it appeared that the portion in the solar vertical was brighter, whiter, and was intersected by the brilliant upper contact arc. As the solar altitude decreased however, this portion separated from the 22°-halo, and it was evident that Parry's arc (6) was present, at first being very close to the 22°-ring. It was later lost in the glare from the contact arc "veil". Wegener's [20] theory shows a separation of $<1°$ at a solar elevation of 37.6° and the observations are thus in good agreement.

At this first observation, the 46°-halo (2) was not present at all, but the infralateral tangential arcs (8) were very bright and colored, especially at their point of closest approach to the sun (the point of "tangency"). By 1320 AST ($h_s$=36.2°), the 46°-halo was very weakly visible, and the points of minimum approach were indeed points of tangency.

Extending below the parhelia (the focal lines of which appeared to be inclined at some 60° or so to the parhelic circle, rather than normal to it) could faintly be detected the arcs of Lowitz (7), appearing as nearly straight lines, perhaps slightly concave toward the sun, and extending toward the 22°-ring as smooth extensions of the parhelic inclination. The arcs merged into the general glare and the point of contact could not be determined; likewise the relative weakness of the arcs combined with the overall glare prevented any determination of color. With the exception of the parts very close to the parhelia, the arcs did not persist clearly for very long, slowly merging with the background illumination.

Very faintly visible at this stage were portions of white anthelic arcs (11), converging approximately toward the anthelic point, but not reaching it. The projection toward the sun was much more difficult to determine and no decision could be reached as to a point of convergence except that it could not be much higher than the 22°-halo in the solar vertical; it could however, have been as low as the sun itself. The eastern arc was especially stronger than the other.

By 1320 AST ($h_s$=36.2°) the 46°-halo had appeared weakly, in sections, strongest in the solar vertical. The whole halo was faintly visible for a while. The anthelic arcs (11) developed more strongly and extended farther toward the anthelic point, quite definitely converging toward it although again not reaching it. They still showed no evidence of color and the extension solarward was still insufficient to define the point of convergence or mergence.

The whole display faded appreciably by 1345 AST ($h_s$=35.4°), particularly the anthelic arcs and eastern

120°-paranthelia. By 1430 ($h_s=32.2°$) however, the anthelic arcs and 120°-paranthelia reached their maximum intensity and extent. The lower circumscribed halo, arcs of Lowitz, and eastern infralateral tangential arc had by this time gone completely, the western infralateral arc and upper circumscribed halo were much weaker and very diffuse, Parry's arc being lost in the diffuseness. The 46°-halo existed faintly in the solar vertical.

By 1510 AST ($h_s=28.8°$) the display was considerably more diffuse and weaker; however in the solar vertical, a short, colored, but diffuse arc (9) was visible (see fig. 4), concave away from the sun, but in contact with the 46°-halo which was still visible in this region. The point regarding its tangency was specifically examined and it was noted down as definitely tangential. Later calculation showed that the circumzenithal arc of Bravais (cf. [19]) should have been separated from the 46°-halo at this solar elevation by about 2½°. This fact, and its diffusely colored appearance and short extension, are all in contradiction with other observations of the circumzenithal arc, which is usually reported as purely and beautifully colored. It is thus possible that the arc was in fact the true tangential arc of Galle [13, 18, 19]. Against this however, is the fact that the arc was not visible earlier despite the presence of oscillating plates (inferred from the presence of the arcs of Lowitz) which produce it. On the other hand, the circumzenithal arc (of Bravais) cannot occur for solar altitudes $>32.3°$ [19, 20], even though the steady plates necessary for its production be present, since total reflection then occurs. It would thus be fortuitous indeed for the arc of Galle to appear suddenly just as the condition for the circumzenithal arc to appear is satisfied. This question cannot be resolved since no measurements or photographs were obtained of the arc.

The display faded out completely (except for weak parhelia) by 1530 AST ($h_s=27.0°$).

The most notable absence throughout the display was the vertical pillar through the sun—no trace of it appeared at any time, despite specific observation for it. Also absent was any form of anthelion on the parhelic circle itself.

A few remarks will here be made about the anthelic arcs. As noted above, the sunward extension of these arcs could not be estimated with any certainty at the time of observation; however on several of the photographs the arc can be faintly traced to very near the top of the 22°-halo, approaching as though the two arcs would meet smoothly, as distinct from intersecting. There are two principal theories for the production of the anthelic arcs: Hastings [6] proposed that they are a reflection of Parry's arc [17, 20] in the end faces of horizontal columns, while Wegener [20] proposed rather more realistically that they are produced by a similar reflection of the circumscribed halo. Visser [19] objected to Hastings' theory on the grounds that Parry's arc [17, 20] is usually rather faint and the small proportion of rays reflected in the end faces is thus unlikely to produce anthelic arcs, which can be quite bright. Since the major part of Parry's arc is produced by ice-columns with principal axes oriented from about 45° to 90° to the incident light, crystals producing a predominance of end reflections (i.e., anthelic arcs) over pure refraction (i.e., Parry's arc) would need to be short; however, short crystals would certainly destroy the very special orientation required for the production of Parry's arc (a pair of prism faces must remain horizontal, thus presenting maximum air resistance and requiring long crystals and no turbulence). It thus appears that the conditions for the production of Hastings' arc are mutually contradictory.

At least two other forms of anthelic arcs have been reported. One (see Liljequist [11]) is not involved here. The other, however, frequently appears in observer's reports as intersecting the sun [1, 16], although it is possible that some, at least, of these result from inaccurate reporting. (It should be noted however that there certainly are arcs which leave the sun at a sharp angle: Visser [19] and Humphreys [8] discuss some of these. Another is reported by Blake [4]. They are not, however, anthelic arcs.)

There are few extensive measurements in existence of the anthelic arcs and thus the all-sky camera photographs have been used to provide some. Because of the difficulties of adapting the system to the cameras used the photographs include some distortion, and also the exact time of the photographs is not known. Nevertheless, the errors involved in assuming a mean time within the known limits, and averaging the positions of the two arcs, are still probably close to the limits of measuring the film. The arcs were accordingly measured and converted to zenith distance, using the parhelic circle as a measure of solar altitude, taken to be 33.8° ($\pm 1.5°$ at the utmost extreme). The theoretical relations of Wegener [20] were then used to determine both Wegener's and Hastings' anthelic arcs. All three curves are replotted on an isogonal zenithal orthomorphic or stereographic projection in figure 5. Such a projection has the advantages of preserving angles of intersection on the celestial sphere, and reproducing circles on the sphere as circles on the projection (see, for instance, E. Hille [7]). It is therefore a most useful projection for representing solar haloes. The relation between the zenith distance $Z$ on the projection, and the zenith angle $z$ of the point on the celestial sphere is given by $Z=R \tan \frac{z}{2}$, where $R$ is the total radius of the horizon on the projection.

It is obvious from figure 5 that the observed curve could have been produced by either theory, the slightly better fit to Hastings' curve near the solar vertical being insignificant in view of the above remarks. The plot does, however, confirm the validity of these theories in producing (geometrically) a curve which fits an observation of the anthelic arcs, such measurements not being very common. (Visser [19] quotes another.)

Although not present in this display, the lower extensions of the anthelic arcs below the parhelic circle and

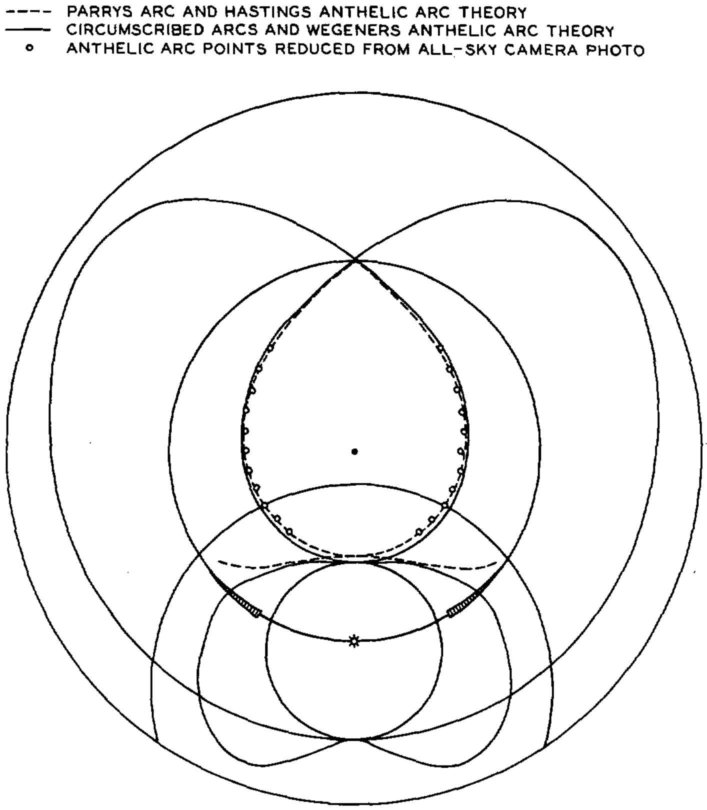


FIGURE 5.—Plot of theoretical haloes for solar altitude of 33.8° with observed anthelic arcs for comparison. Also plotted for comparison are the 22°- and 46°-rings, parhelia and tails, and parhelic circles. A zenithal orthomorphic or stereographic projection is used.

back to the lower solar vertical at the 22°-halo are sometimes observed. These are easily explained by Wegener [20] as the reflection of the lower part of the circumscribed halo; Hastings [6] however, must invoke one of the arcs of Putninš [17] (arc 2–4 of his nomenclature), an arc almost certainly never observed in full.

## 3. DISCUSSION

The Fairbanks halo display was characterized by two significant points:

(1) the absence or great weakness of haloes produced by randomly oriented or tumbling crystals (22°- and 46°-rings and vertical pillar)

(2) The presence of a number of haloes produced by long columnar ice crystals, some requiring stable crystal orientations of a very special kind, together with plate-haloes (parhelia, paranthelia, Lowitz' arcs, upper 46°-"contact" arc, and probably a contribution to the parhelic circle).

The first point is indicative of the absence of short-column crystals and of turbulence, both of which would result in random orientations of the principal axes of the crystals. The second point confirms the presence of distinct plates (having vertical principal axes) and long columns (with horizontal principal axes).

The formation and development of ice crystals at various temperatures has been studied by a number of workers (see [9–12, 15, 19] and the bibliographies therein for reviews). The above observations as to crystal types present would appear to indicate a temperature of formation between −10° C. and −30° C.; at lower temperatures the crystal size becomes too small to give the necessary preferred orientations, while at higher temperatures the proportion of long columns falls off. Comparison with the upper atmosphere temperatures over Fairbanks at 1400 AST shows that such a temperature range corresponded to a height range of about 8,000–20,000 ft. From an examination of the radiosonde aerological data, Dr. T. Ohtake of this Institute has suggested the possible cloud height to be somewhere between 13,000 and 16,000 ft., certainly well within the limits indicated by the haloes, but rather lower than might be expected for cirriform cloud. Kobayashi [9] has investigated the growth of ice crystals and has shown that within this temperature range, the crystals, whether initially plates or long columns, eventually develop to an axis ratio of 0.8–1.5, a development which would destroy the preferential orientation of the principal axes of the crystals and break up the display, unless, of course, formation of the crystals were maintained.

The winds between 10,000 and 20,000 ft. were of speeds less than 20 kt., and from a predominantly SE direction. It is known from observations of haloes produced in "ice-needle" clouds at almost ground level, that extensive displays can occur with such wind speeds [4, 11], the crystal orientations apparently remaining sufficiently stable.

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## REFERENCES

1. F. J. Bavendick, "Beautiful Halo Display Observed at Ellendale, N. Dak.," *Monthly Weather Review*, vol. 48, No. 6, June 1920, pp. 330–331.
2. L. Besson, "La Théorie des Halos," *Annales de l'Observatoire de Montsouris*, vol. 9, 1908, pp. 343–372.
3. L. Besson, "Sur la Théorie des Halos," *Annales de l'Observatoire de Montsouris*, vol. 10, 1909, pp. 143–201.
4. J. R. Blake, "Solar Halos in Antarctica," *Australian National Antarctic Research Expedition Report* No. 59, Ser. A, vol. 4, Glaciology, Antarctic Div., Melbourne, 1961, 48 pp.

5. A. Bravais, "Mémoire sur les Halos et les Phénomènes Optiques qui les Accompagnent," *Journal de l'Ecole Royale Polytechnique*, 31 cahier, tom. 18, Paris, 1847, pp. 1–270.
6. C. S. Hastings, "A General Theory of Halos," *Monthly Weather Review*, vol. 48, No. 6, June 1920, pp. 322–330.
7. E. Hille, *Analytic Function Theory*, vol. 1, Ginn and Co., 1959, (Chapter 2).
8. W. J. Humphreys, *Physics of the Air*, 3d edition, Chapter 4, 5, pp. 501–546, McGraw-Hill Book Co., Inc. 1940, reprinted, Dover 1964.
9. T. Kobayashi, "Experimental Researches on Snow Crystal Habit and Growth by Means of a Diffusion Cloud Chamber," *Low Temperature Science*, (Japan) Ser. A, vol. 16, 1957, pp. 1–35.
10. T. Kobayashi, "The Growth of Snow Crystals at Low Supersaturations," *Philosophical Magazine*, Ser. 8, vol. 6, 1961, pp. 1363–1370.
11. G. H. Liljequist, "Halo Phenomena and Ice-Crystals," *Norwegian-British-Swedish Antarctic Expedition, 1949–1952, Scientific Results*, vol. 2, Part 2A, Special Studies, Norsk Polarinstitutt, Oslo, 1956, 85 pp.
12. B. J. Mason, "The Physics of Clouds," *Oxford Monographs on Meteorology*, vol. 1, Oxford University Press, 1957, 481 pp.
13. S. Melmore, "Ice-Crystal Halos," *Nature*, vol. 153, Feb. 1944, p. 166.
14. R. Meyer, "Die Haloerscheinungen," *Probleme der Kosmischen Physik*, vol. 12, Grand, Hamburg, 1929, 168 pp.
15. U. Nakaya, *Snow Crystals, Natural and Artificial*, Harvard University Press, 1954, 510 pp.
16. J. M. Pernter and F. M. Exner, *Meteorologische Optik*, Part 3, Ch. 1, pp. 244–444, "Die Halo-oder Ringerscheinungen," 2d ed. W. Braumüller, Universitäts-Verlagsbuchhandlung, Ges. m.b.H., Wien und Leipzig, 1922.
17. P. Putninš, "Der Bogen von Parry und andere unechte Berührungsbogen des gewöhnlichen Ringes," *Meteorologische Zeitschrift*, vol. 51, 1934, pp. 312–331.
18. D. B. O. Savile, "Ice-Crystal Haloes," *Nature*, vol. 153, Jan. 1944, p. 25.
19. S. W. Visser, "Die Haloerscheinungen," *Handbuch der Geophysik*, vol. 8, Kap. 15, Borntraeger, Berlin, 1960, pp. 1027–1081.
20. A. Wegener, "Theorie der Haupthalos," *Aus der Archiv der Deutschen Seewarte*, vol. 43, No. 2, Jahrgang 1925, Hamburg, 1926.
21. E. W. Woolard, "The Boulder Halo of January 10, 1918," *Monthly Weather Review*, vol. 48, No. 6, June 1920, pp. 331–332. (See also *Monthly Weather Review*, vol. 46, No. 1, January 1918, p. 22.)

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